High-capacity mmW point-to-point radio links for 5G and beyond: >100 GHz, >100 Gbps

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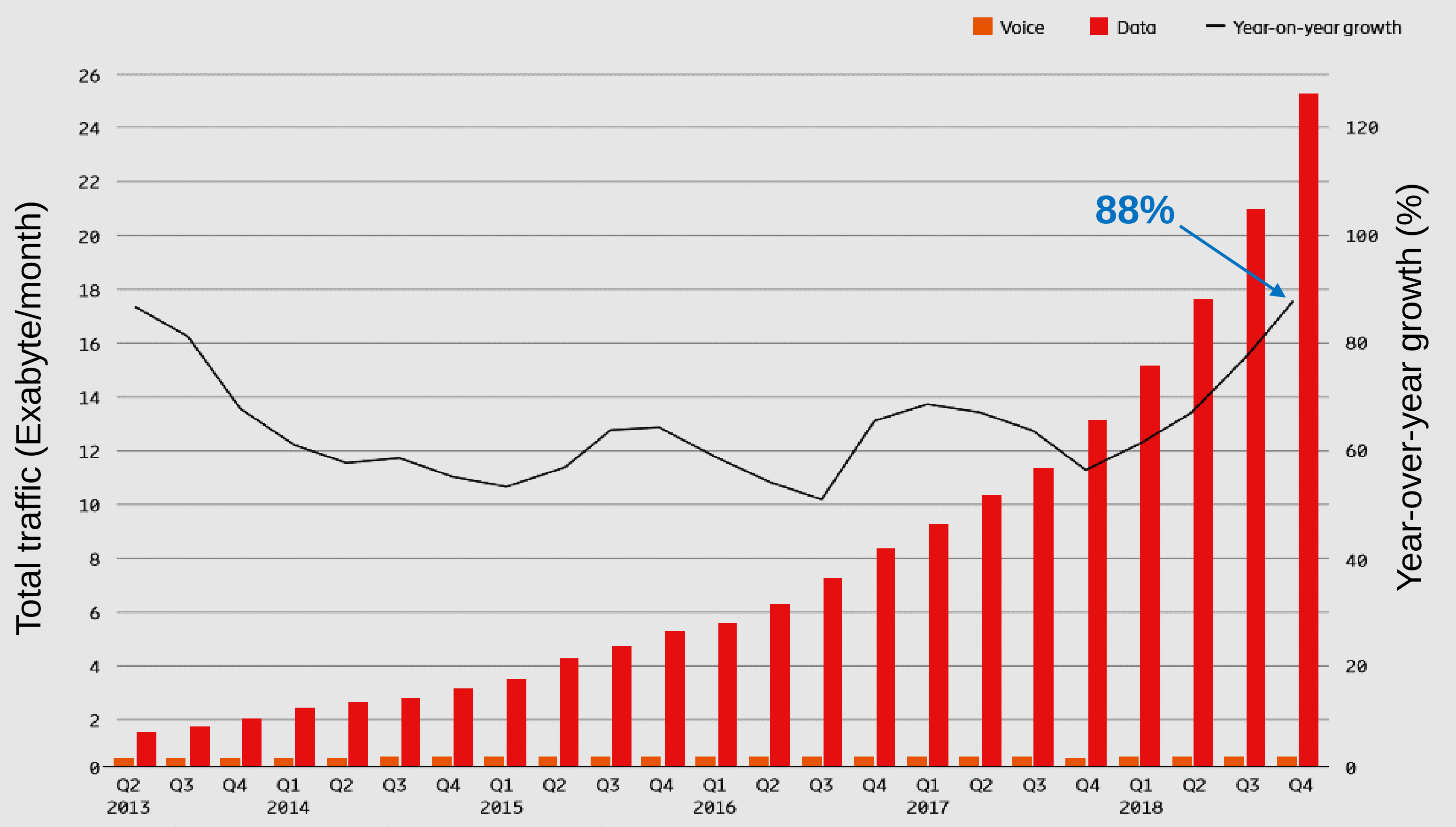
Outline

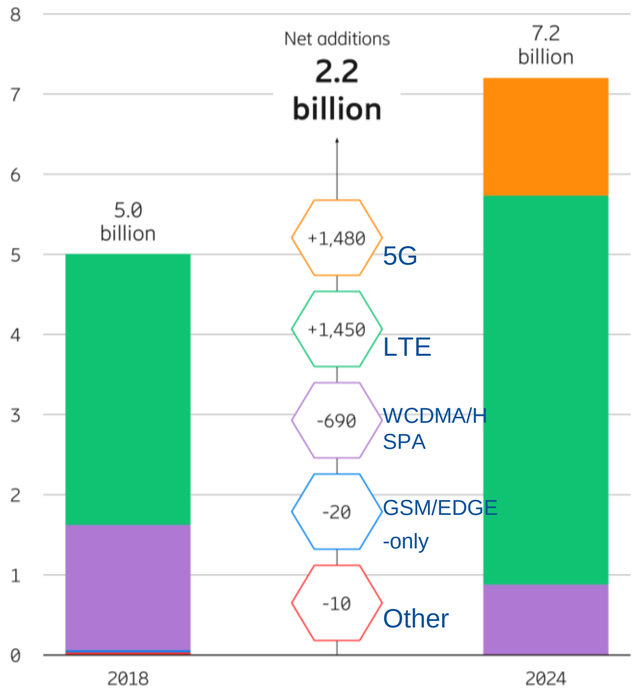
- Background
- Spectrum Horizon
- Challenges with mmW & sub-mmW
- Ex. D-band research & development
- Conclusions and future perspective

Global mobile traffic growth

- Based on measurement from commercial networks



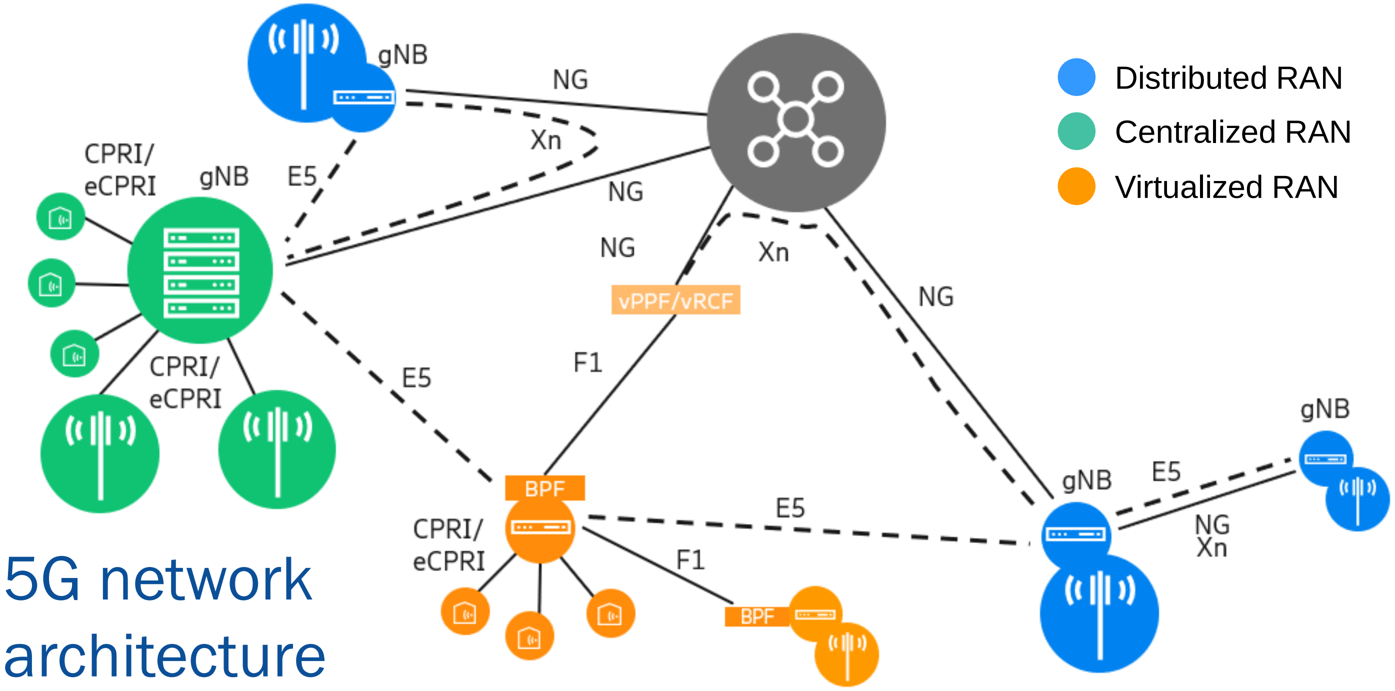
Source: Ericsson (Q4 2018) (Total traffic = UL+DL including VoIP but DVB-H, Wi-Fi or Mobile WiMAX)



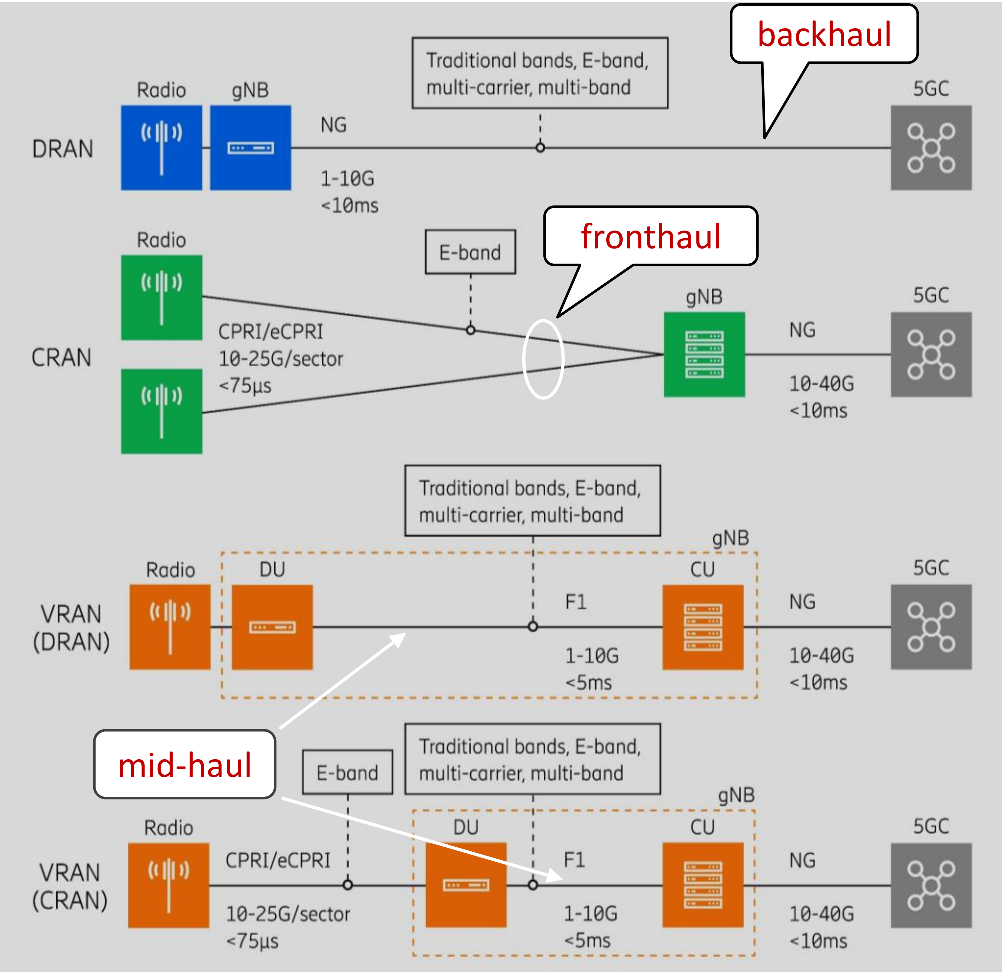
Smartphone subscriptions by technology
source: Ericsson (2018)

Evolution of mobile networks

- Evolving in:
  - Network dimensioning and architecture
  - Capacity



5G network architecture



All point-to-point links, *the solid lines*, can be realized in microwave

Future transport capacity needs

Backhaul capacity per site in Distributed RAN

	2018 Low – high sites	2022 Low – high sites	2025 Low – high sites
Urban	150 Mbps – 1 Gbps	450 Mbps – 10 Gbps	600 Mbps – 20 Gbps
Suburban	100 Mbps – 350 Mbps	200 Mbps – 2 Gbps	300 Mbps – 5 Gbps
Rural	50 Mbps – 150 Mbps	75 Mbps – 350 Mbps	100 Mbps – 600 Mbps

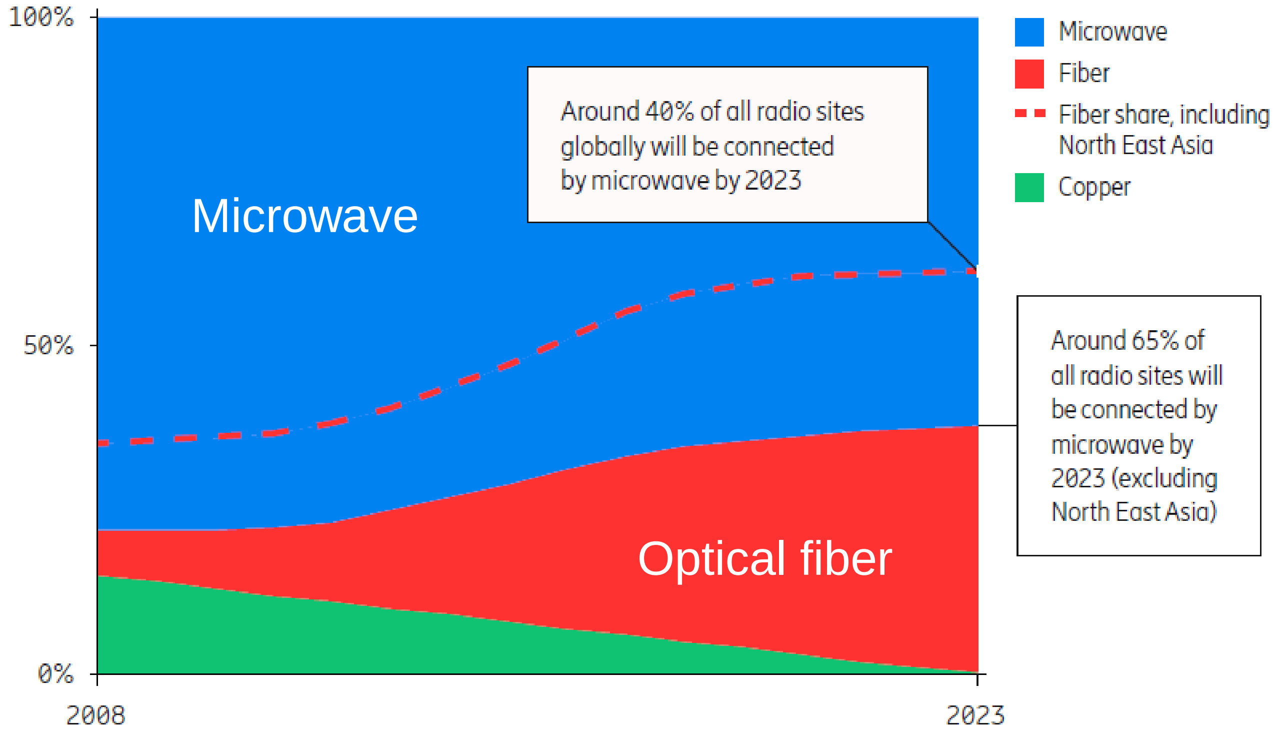
C2 (eCPRI) capacity in Centralized RAN

	2022 Low – high sites	2025 Low – high sites
Massive MIMO (1 sector)	10 - 15 Gbps	15 - 25 Gbps
Massive MIMO (3 sector)	15 - 25 Gbps	25 - 40 Gbps

Source Ericsson (2018)

Microwave products capable to support the 2025 need available today!

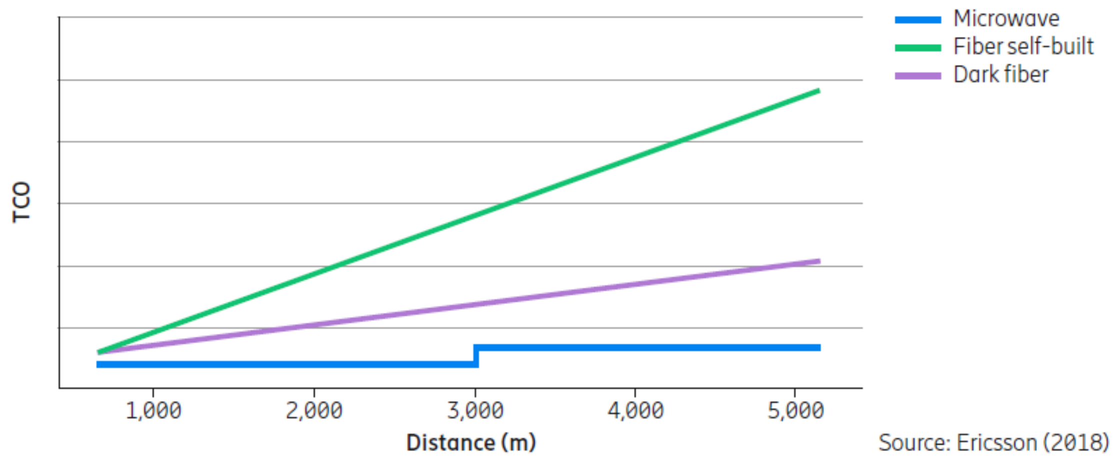
Global backhaul media distribution



Source: Ericsson (2018)

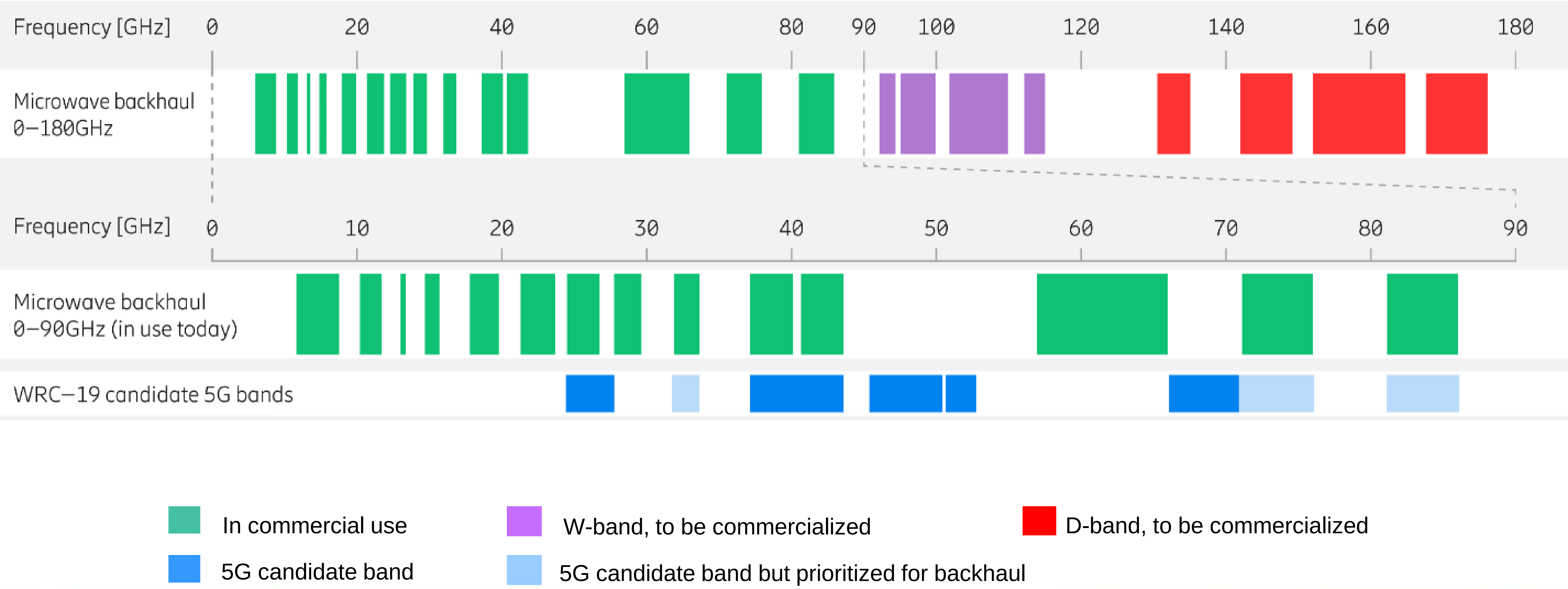
Example:

Total Cost of Ownership for a 10 Gbps link in Germany



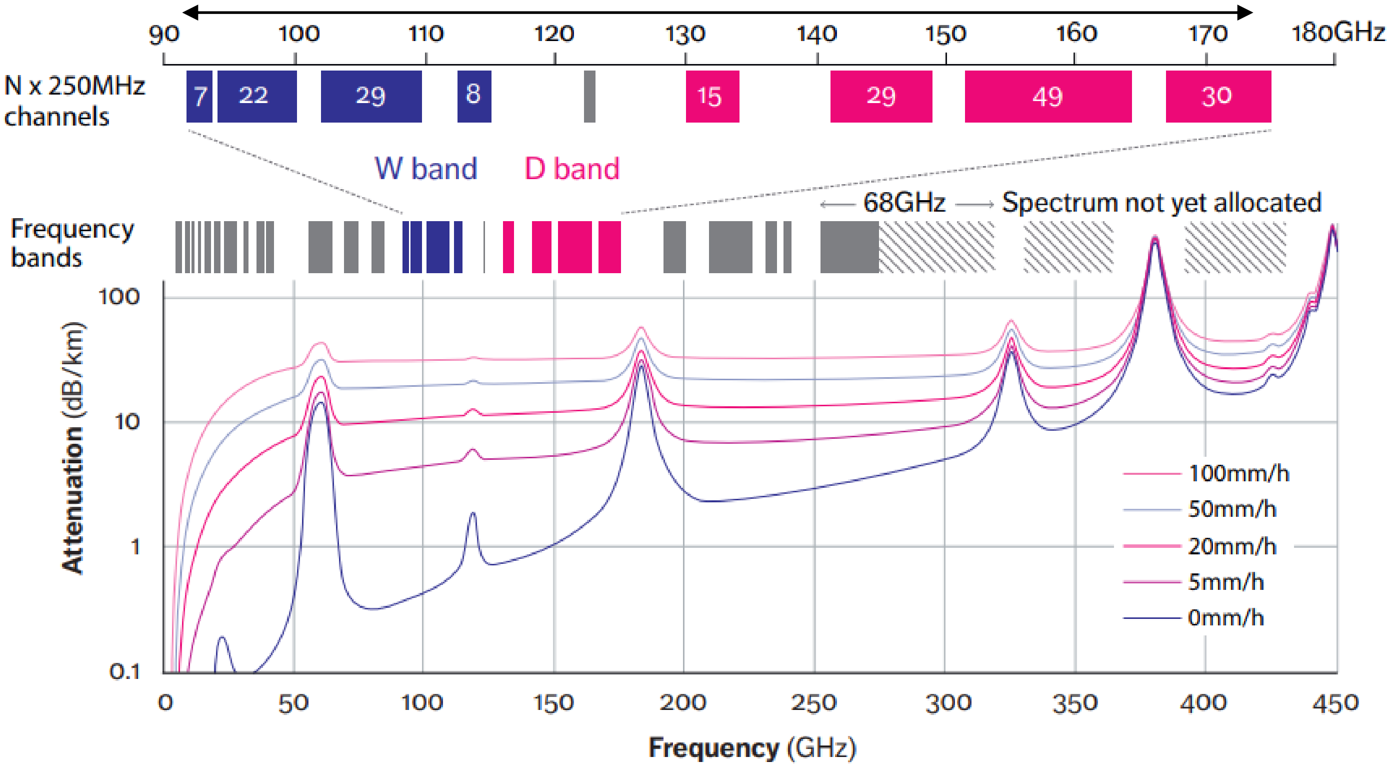
Source: Ericsson (2018)

Spectrum Horizon

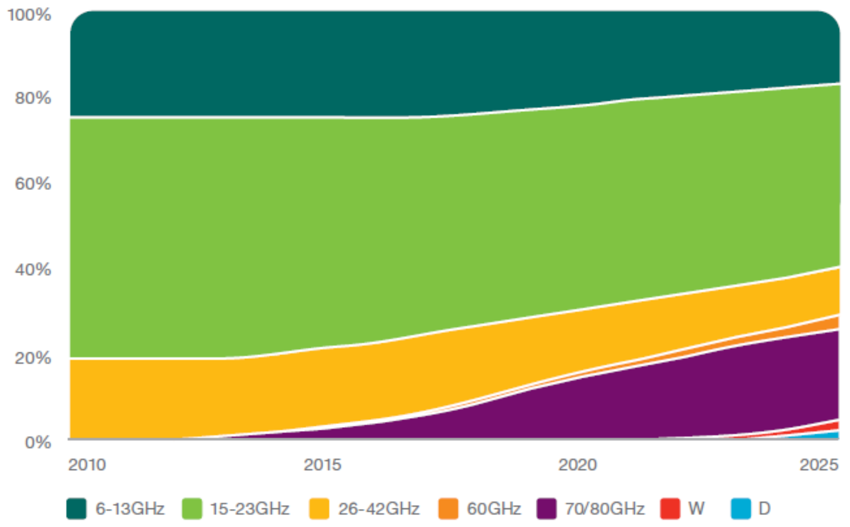


The W-band and the D-band

In total 46.5 GHz for fixed wireless application



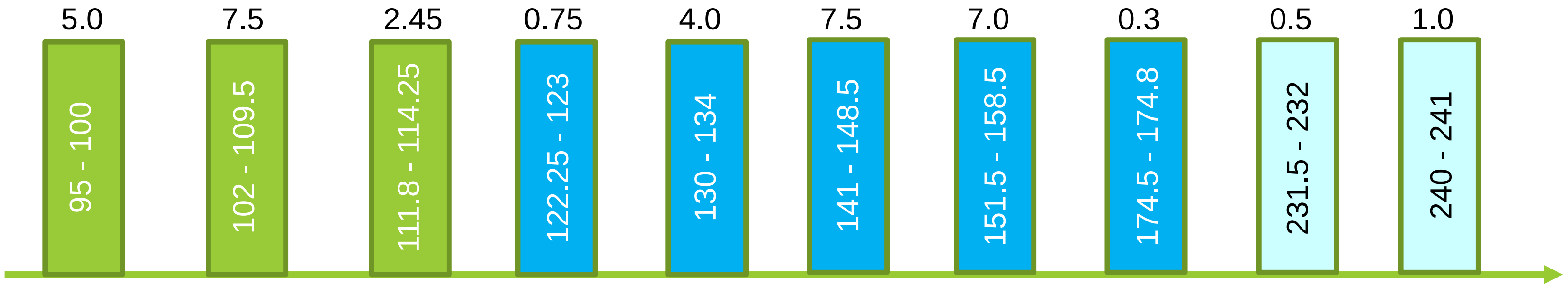
Source: Ericsson Technology Review 2017, https://www.ericsson.com/assets/local/publications/ericsson-technology-review/docs/2017/etr-beyond-100ghz.pdf



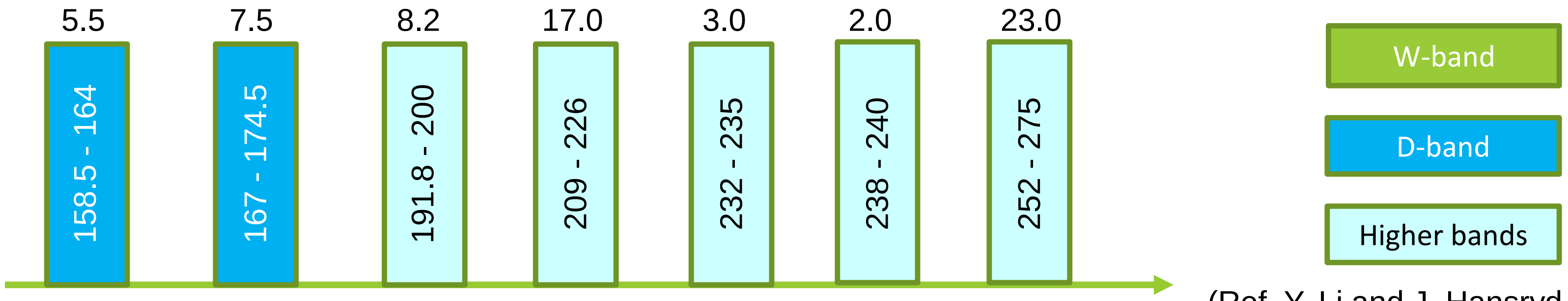
Deployment share per frequency
Source: Ericsson (2017)

FCC Spectrum Horizon: *95-275 GHz for FS*

(a) Bands with light-license (similar to the E-band), totally 36 GHz for fixed service



(b) Bands with strict-license (similar to the conventional bands), totally 66.2 GHz

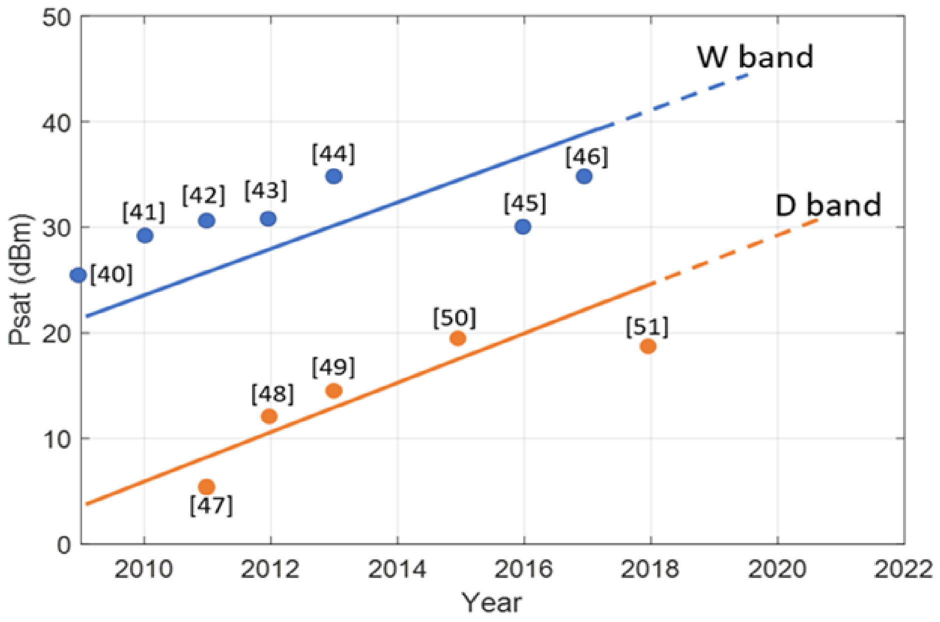


(Ref. Y. Li and J. Hansryd, APMC 2018)

Our next battle field for PtP links is towards sub-millimeter-wave!

Challenges with mmW & sub-mmW

- The output power of solid-state amplifiers decreases with frequency, generally as $f^{-\alpha}$ (α=2~3)
  - Loss 10+ dB from the W-band to the D-band (frequency doubling)
  - The power level is improved by nearly 20+ over the last 10 years
    - Approximately 2dB improvement each year!

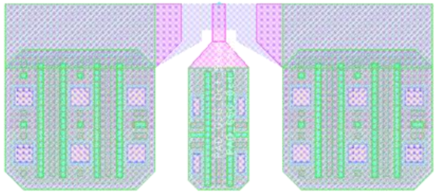


Source; Sining An (2018)

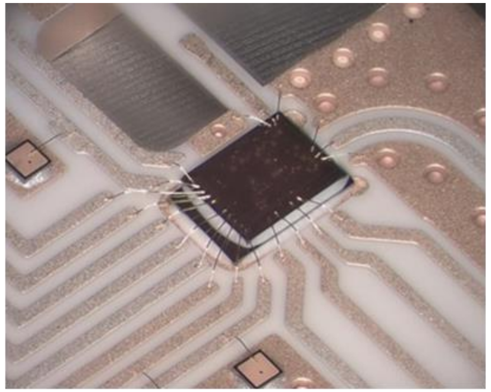
Challenges with mmW & sub-mmW

- Chip interconnect and packaging become increasingly difficult, particularly for Si-based MMICs
  - antenna on-chip or in package if possible!
- Unwanted resonance modes may easily develop in MMICs substrates
- Modeling is increasingly difficult at high frequencies
- Phase noise increases, typically by 6 dB per frequency doubling
- Receiver noise figure increases

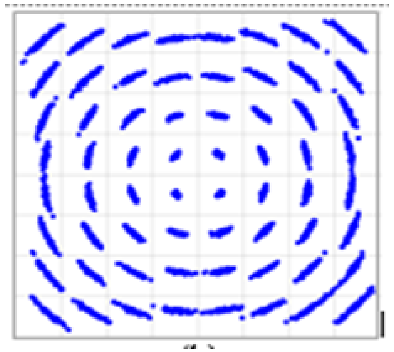
➔ *S/N degrades fast with frequency!*



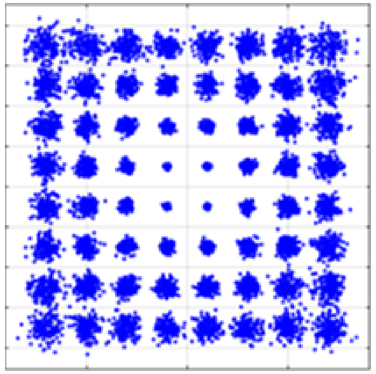
D-band RF pad, 30x60 μm^2, challenging for wire bonding



Wire-bonding, E-probe, backshort for transition, mmW substrate



Phase noise impact



AM & PM white noise

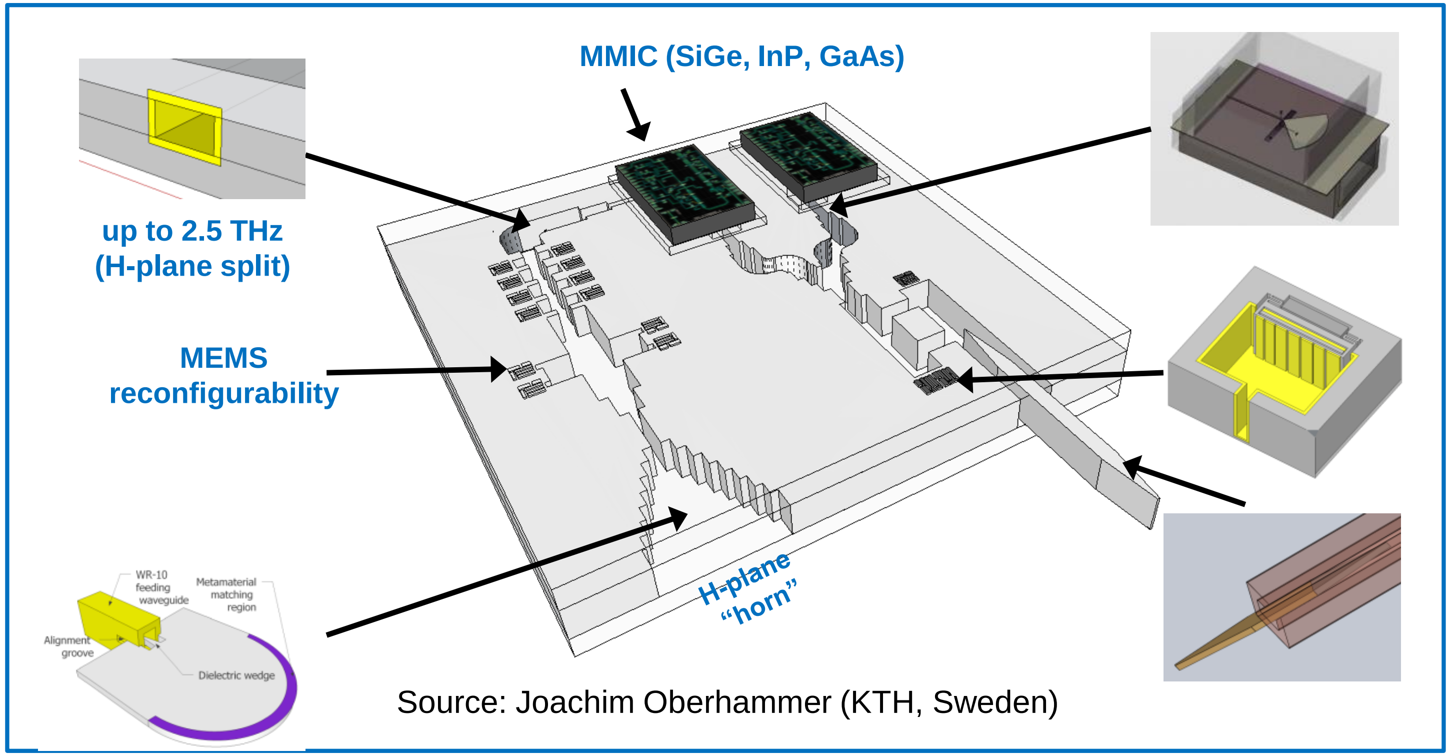
How to transfer the "precious" mmW RF power from MMIC to antenna port?

The solution to be developed must be:

- Volume manufacturable
  - Automatic assembly, good repeatability (= high yield), tolerable (= insensitive to process variations), etc.
- Commercially affordable

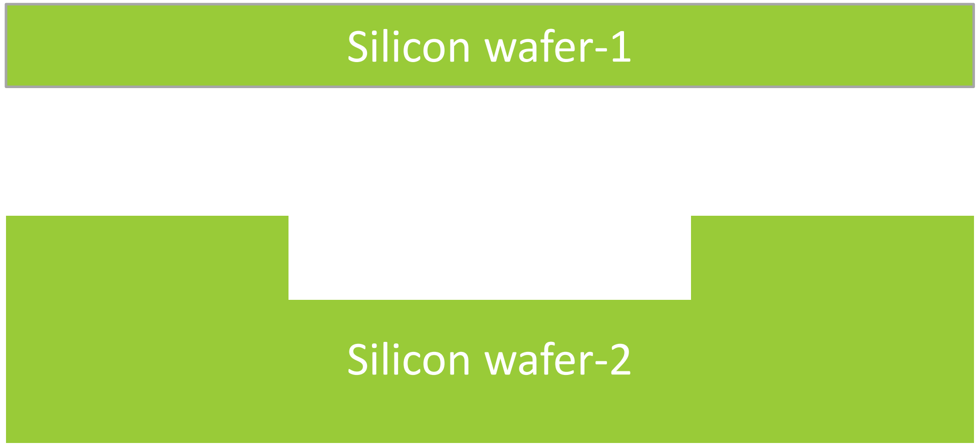
Heterogenous system integration on micromachined platform

- Ultra-low loss THz waveguide, silicon micromachined
- Embedded high-Q passives (e.g., filter, diplexer, power splitter/combiner)
- MEMS-based tunable components, e.g., phase shifter, filters
- D-band Tx/Rx modules successfully demonstrated (November, 2018)
  – EU Horizon-2020 project, ***M3TERA*** (2015-2018)



Source: Joachim Oberhammer (KTH, Sweden)

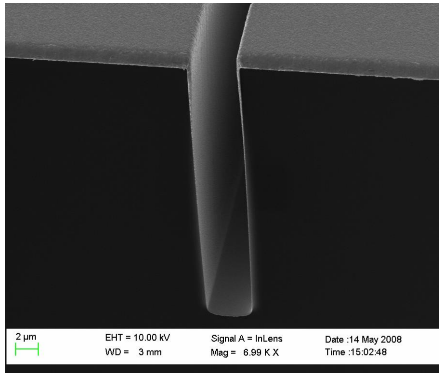
Silicon Micromachined Waveguide

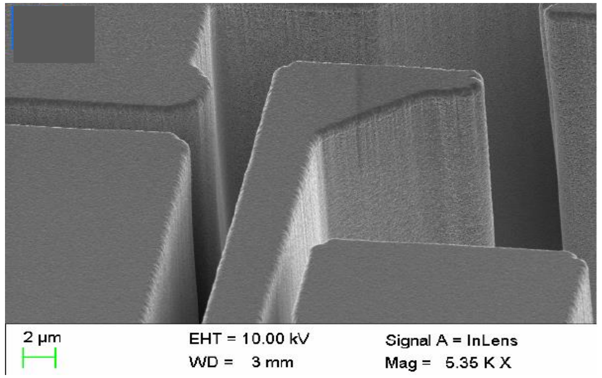


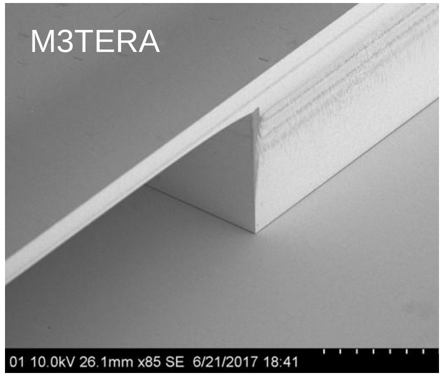
- ➢ Deep-etching
- ➢ Wafer bonding

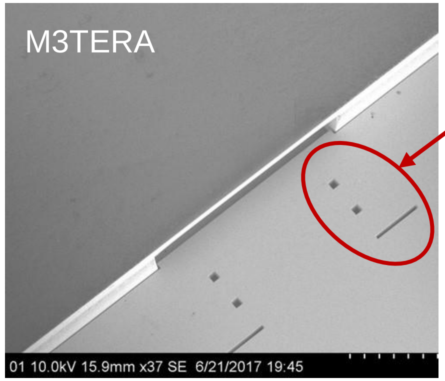
- H-plane split ➔ MMIC placed in H-plane
- H-plane MMIC to waveguide transition is necessary!

Example structure:





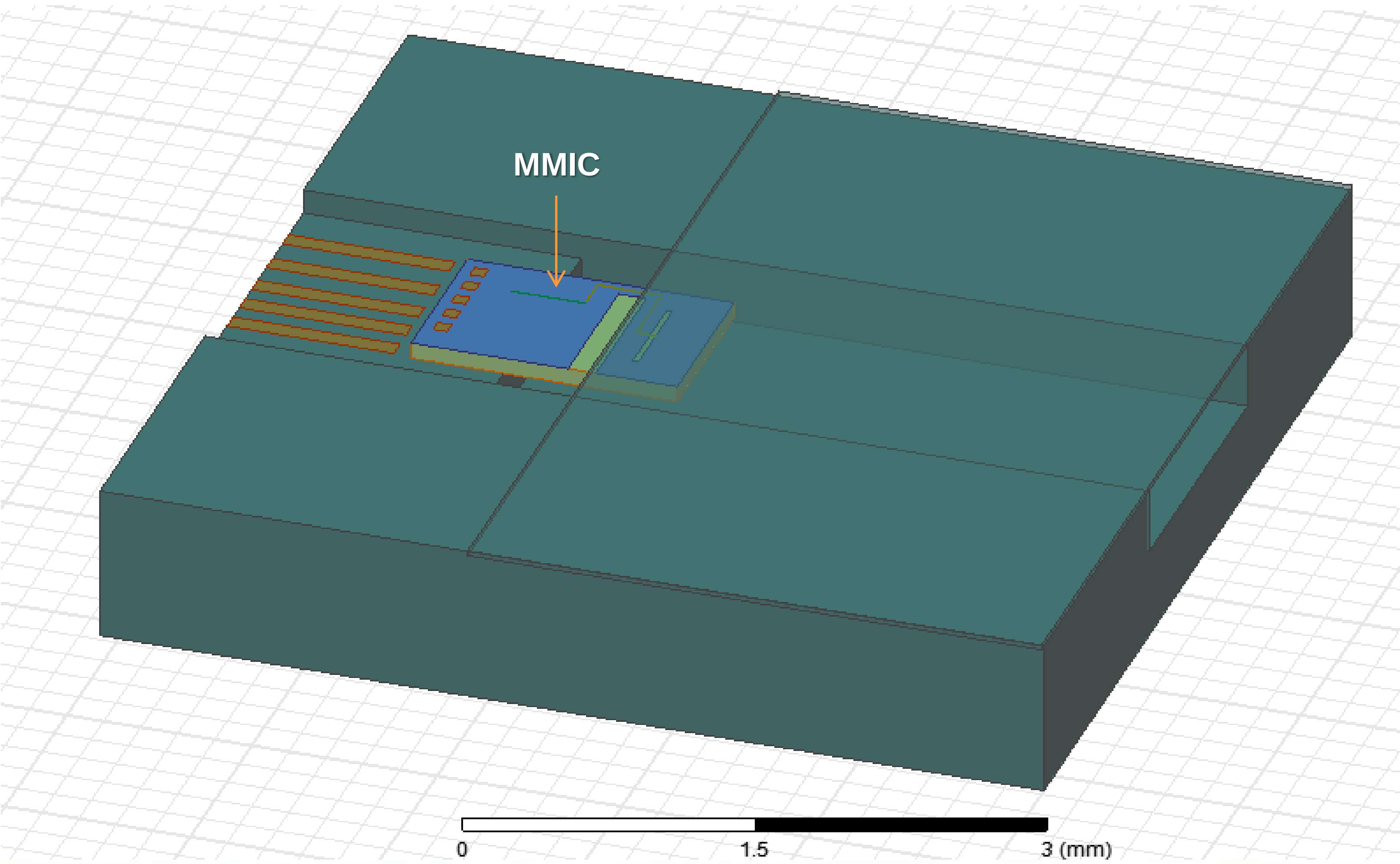


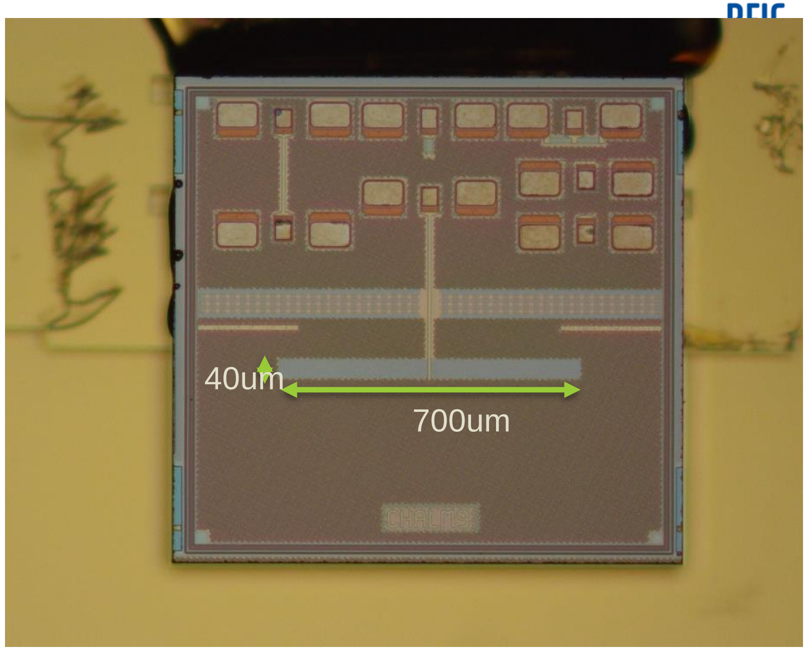


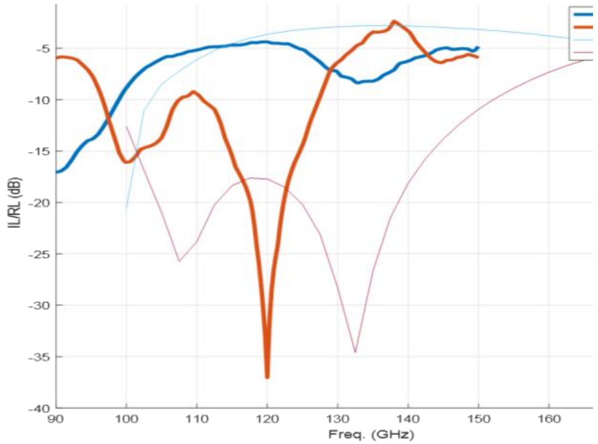
ficucial marks for automatic assembly

Source: Joachim Oberhammer (KTH, Sweden)

MMIC to waveguide transition

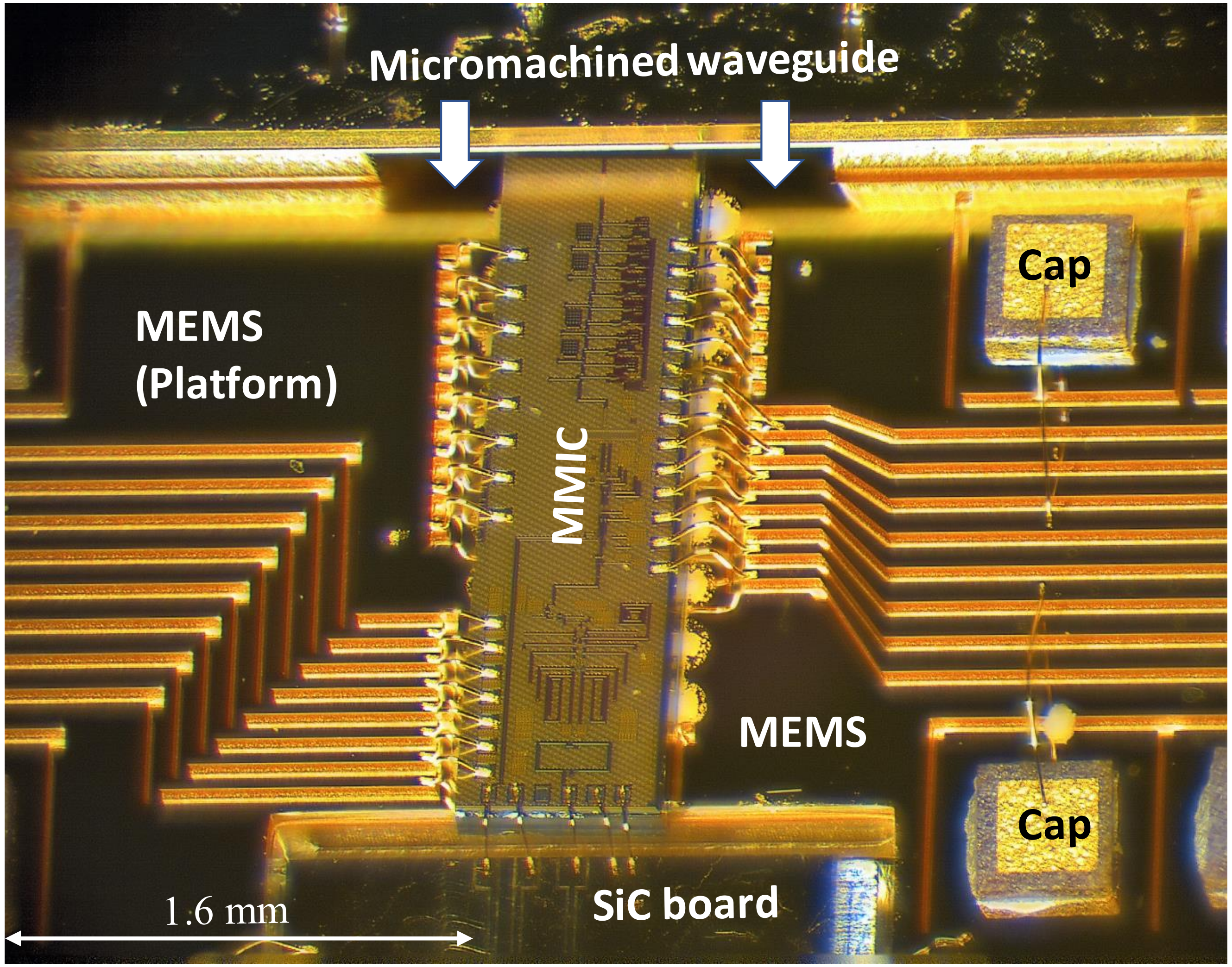






D-band Tx/Rx modules in the micromachined platform

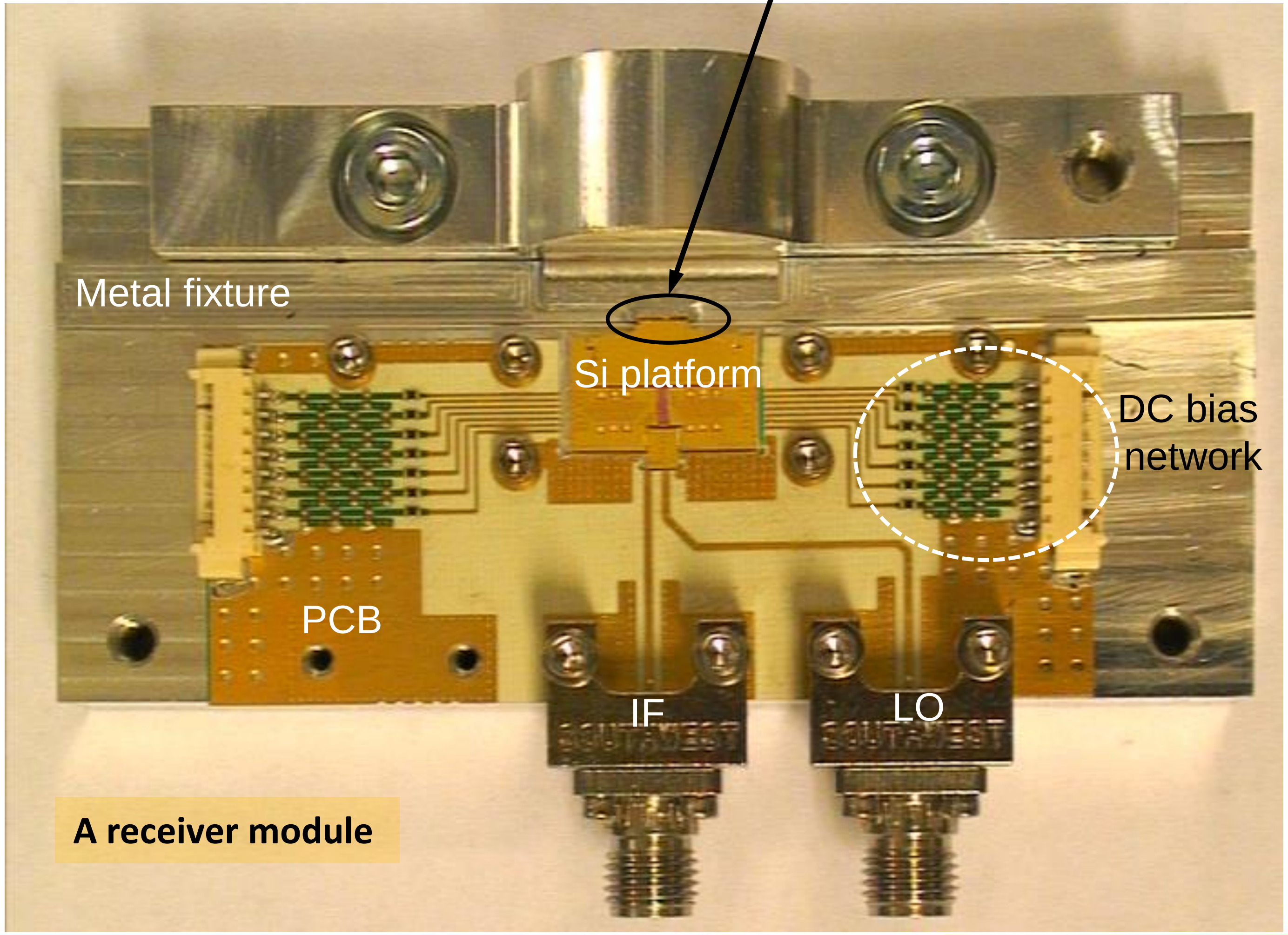
- MMICs in 0.13µm SiGe HBT (from Infineon)
- Micromachined platform with DC, IF and LO routing
- Non-gavanic transition between MMIC and the waveguide
- Automatic assembly of the MMIC and the passive components



Proof-of-concept demonstrator

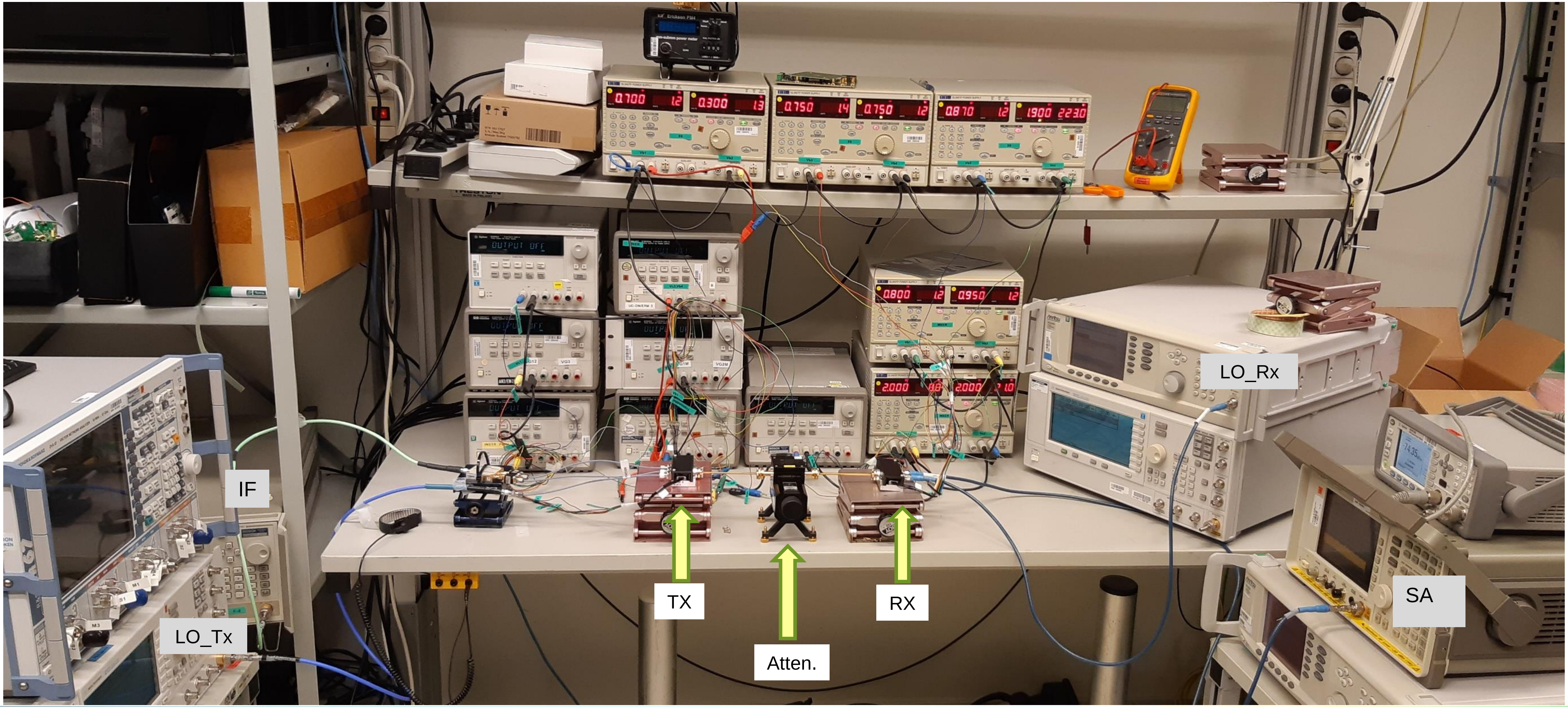
- Example of a completely assembled D-band front-end module (120-150 GHz)
- Circuits and modules developed in the M3TERA project
- Dedicated design for the transition from the micromachined Si chip to a metal waveguide (patent application filed April 2019)

Micromachined Si chip-to-antenna transition

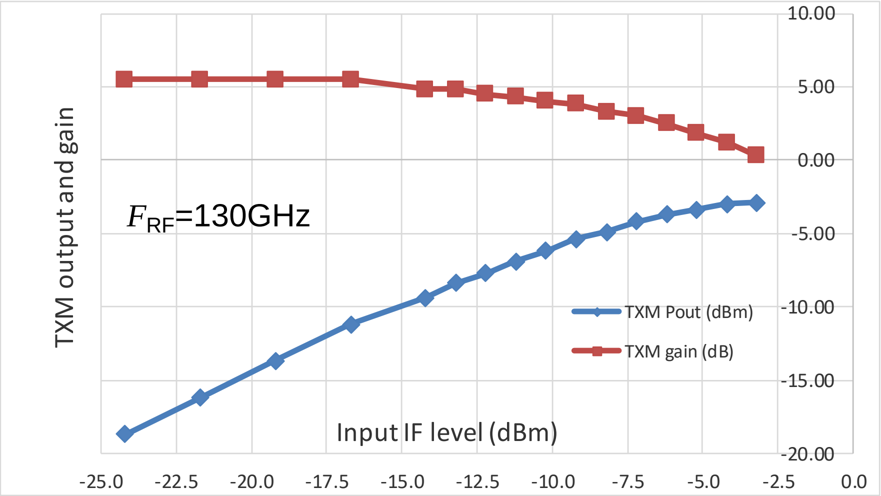


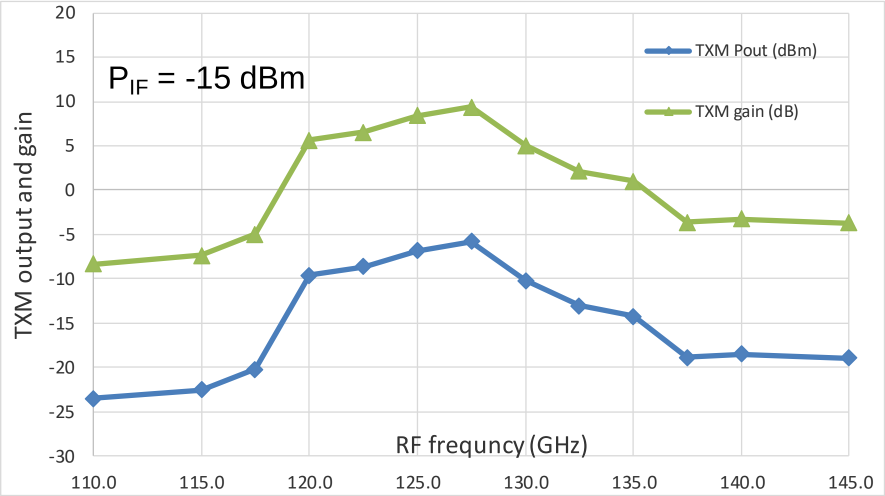
A receiver module

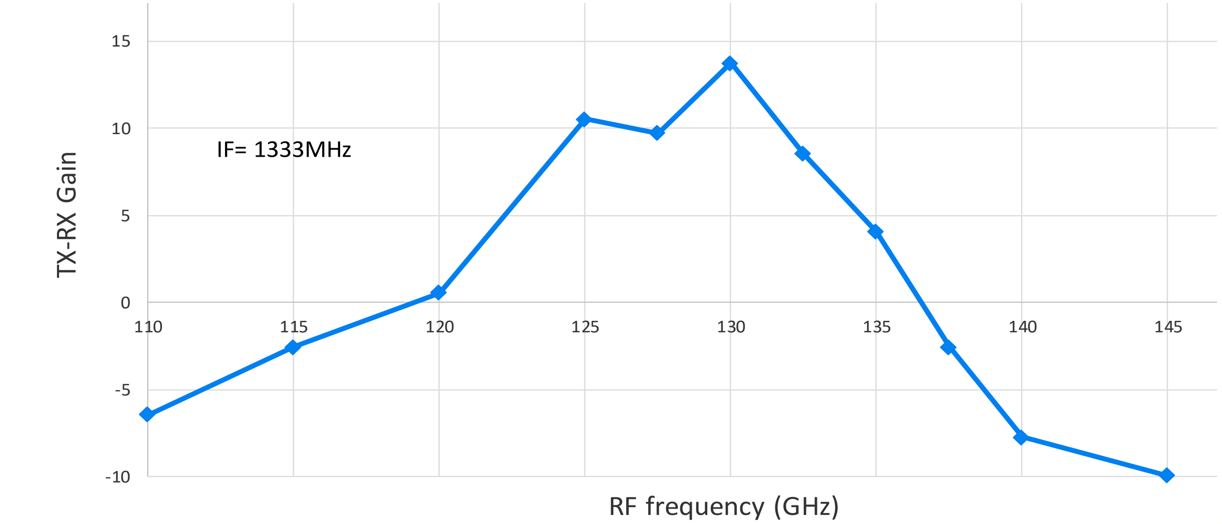
Link test setup



CW test results



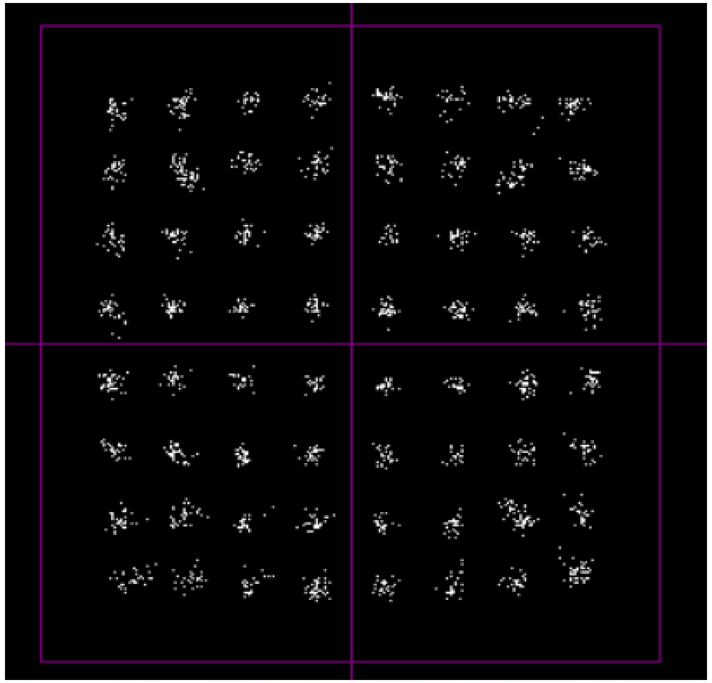


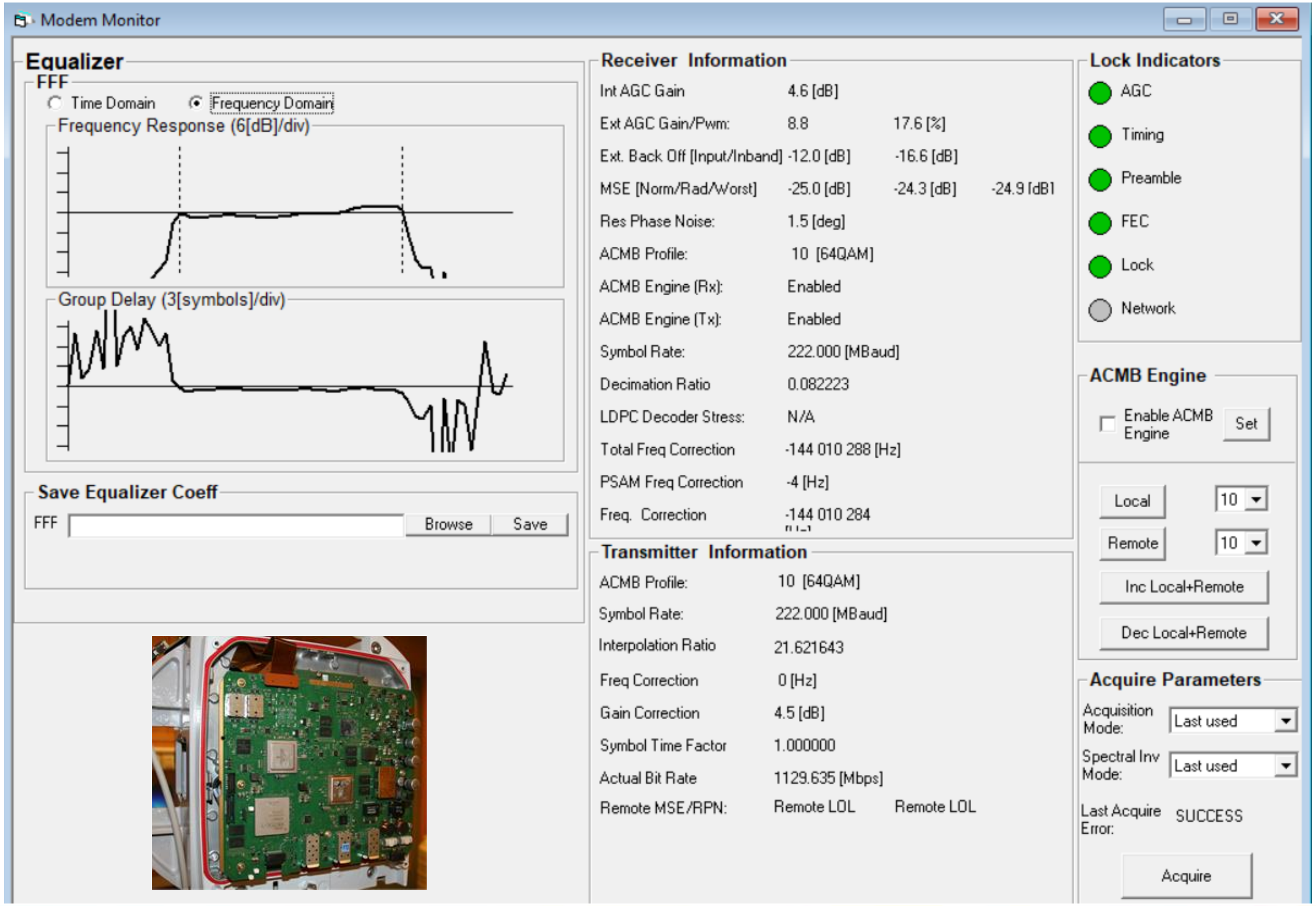


- Peak-gain frequency depends on DC bias
- Bandwidth depends on DC-bias

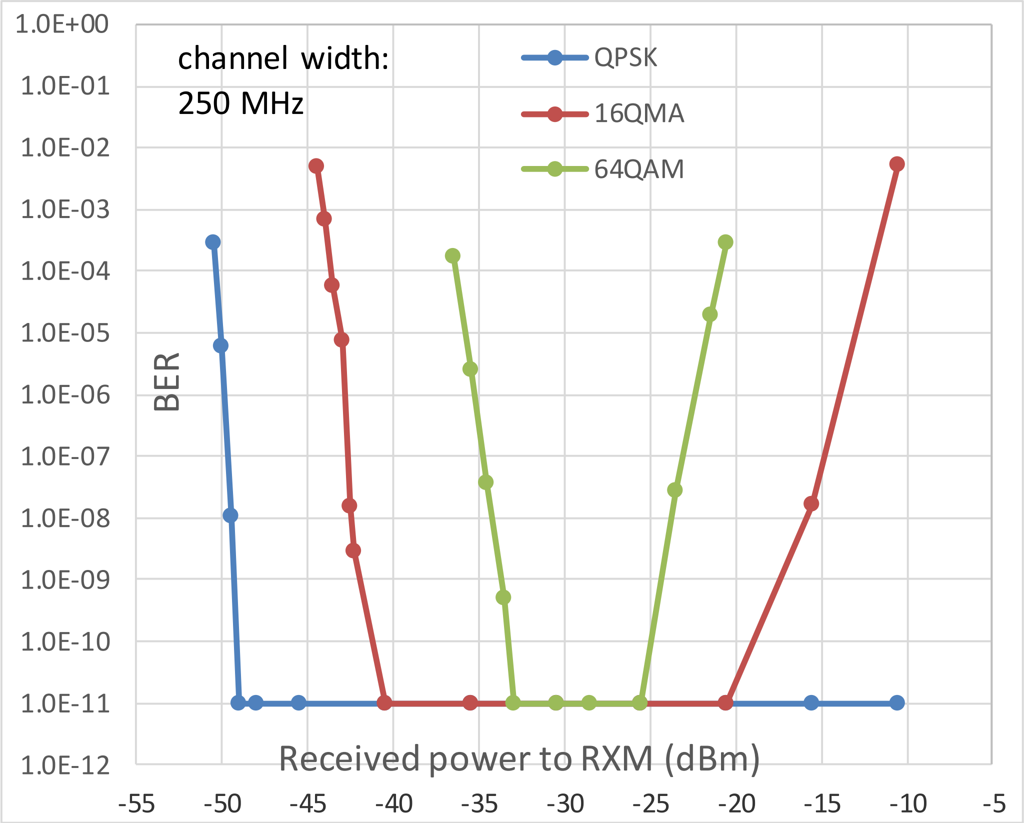
Real-time data transmission

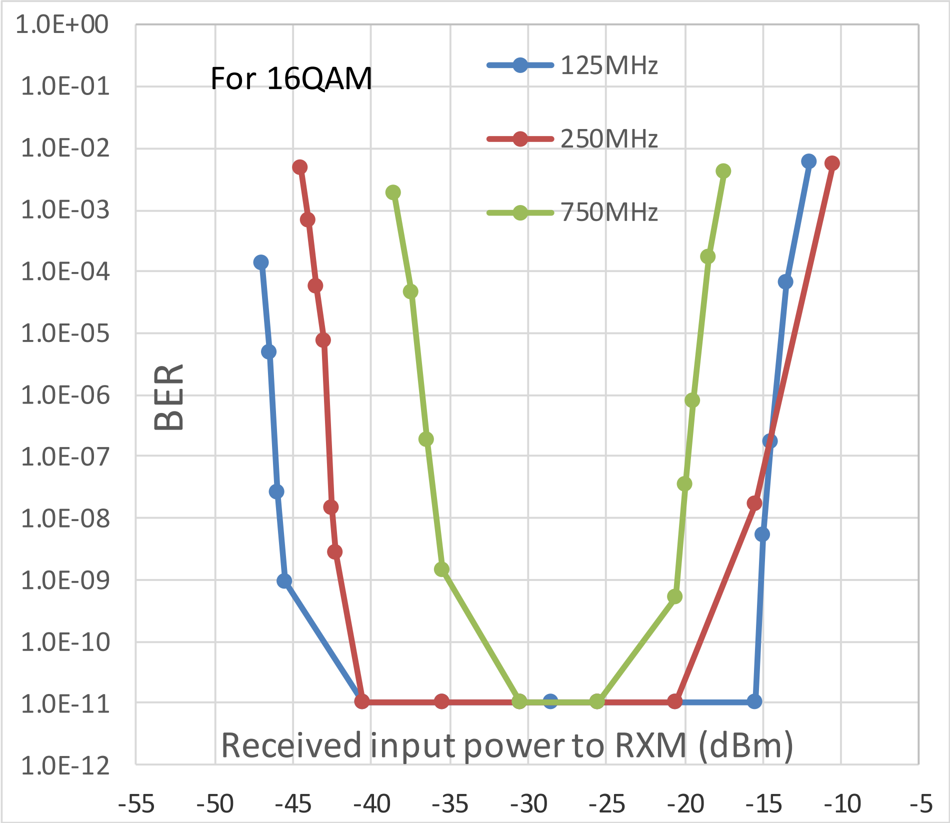
- Using Ericsson's Modem for commercial products



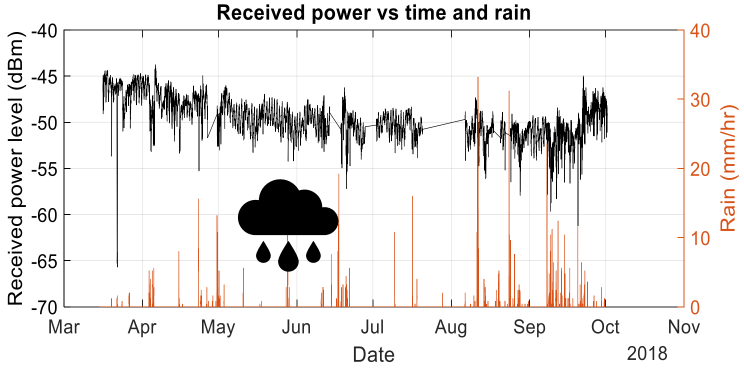


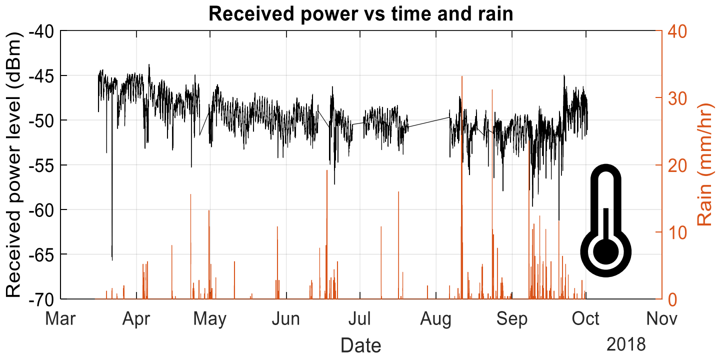
Measurement results

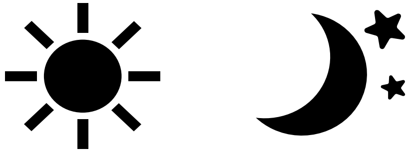




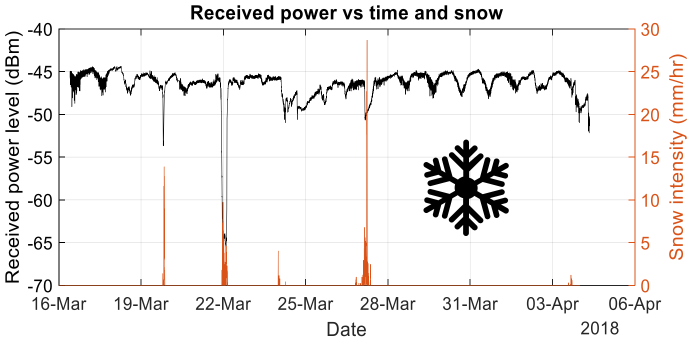
Outdoor D-band link, *long-term measurement*





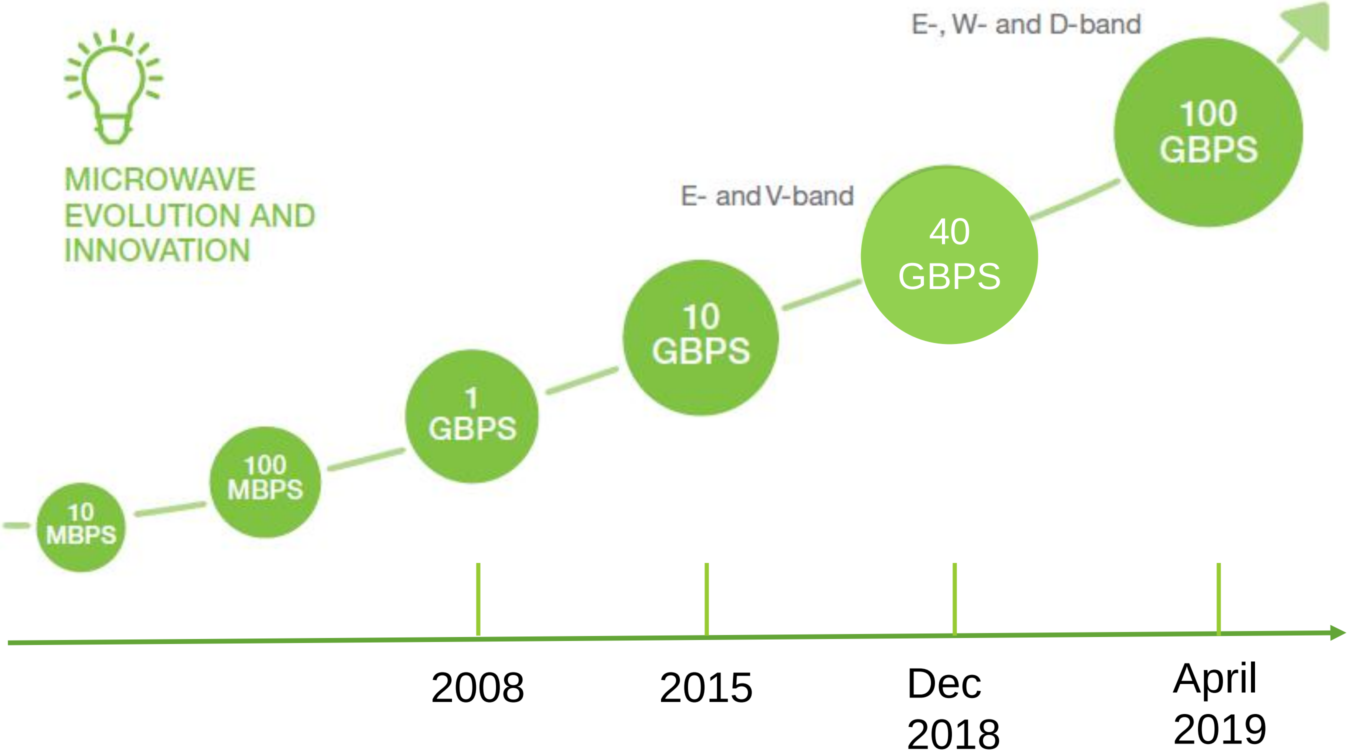


Day-night variation



Ref. *M. Hörberg, Y. Li, V. Vassilev, H. Zirath, and J. Hansryd, "A 143 GHz InP-Based Radio Link Characterized in Long-Term Outdoor Measurement," Asia-Pacific Microwave Conference (APMC), 2018, pp. 234-236*

Breaking the 100 Gbps barrier



Spectrum efficiency required for 100 Gbps

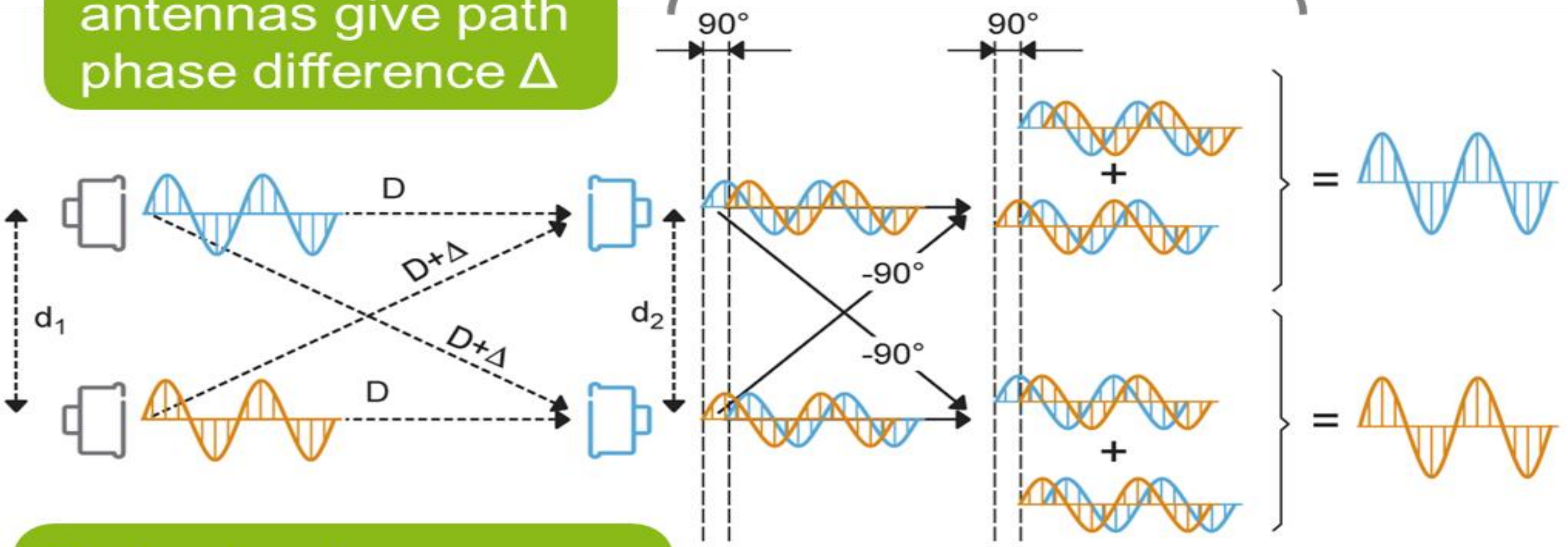
Source: Ericsson (2017)

- ~ 40 bps/Hz spectrum efficiency is required to achieve 100 Gbps using a ~2.5 GHz channel
- Line-of-sight MIMO is necessary in addition to polarization multiplexing

Line-of-sight MIMO

Adaptive signal processing

Spatially separated antennas give path phase difference Δ



Optimal antenna separation: $d_1 d_2 = D\lambda/2$ give $\Delta = 90^\circ$

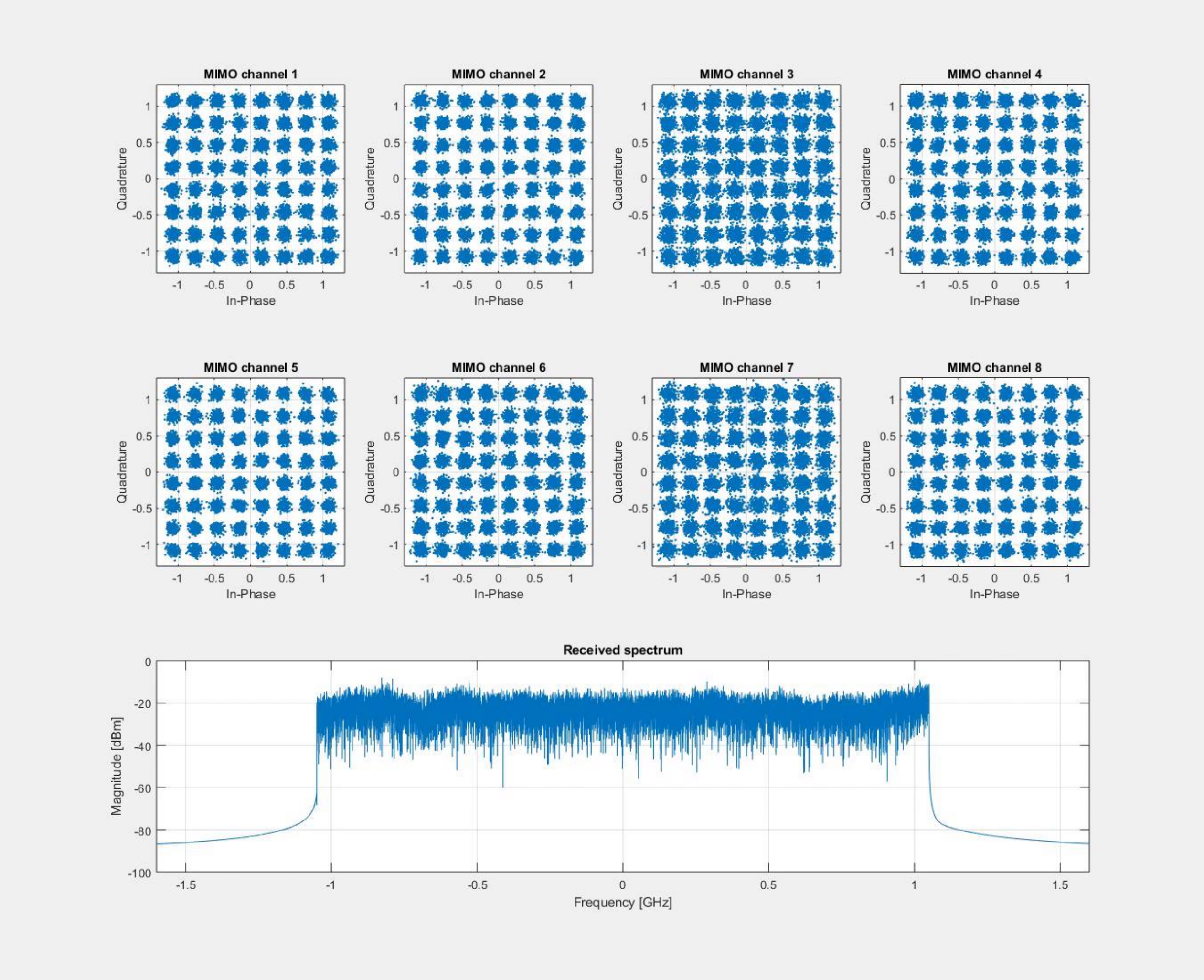
Line-of-sight MIMO setup in Athens

- 8x8 LoS-MIMO (4 spatial + 2 pol.)
- Using commercial E-band radios (Ericsson)
- Hop distance, 1.5 km
- Optimal antenna separation, 1.72 m

100+ Gbps using single carrier frequency

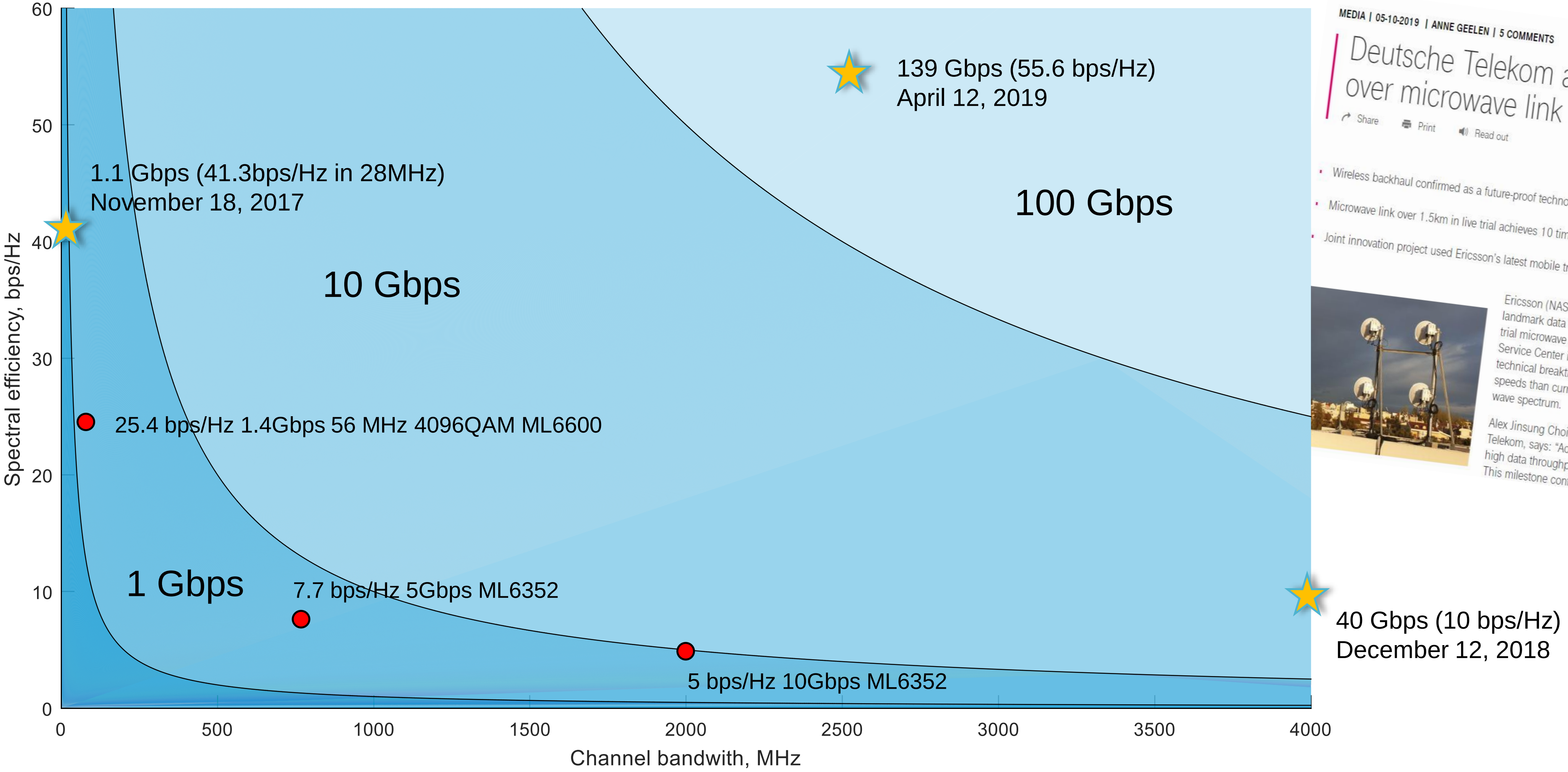
- First 100+ Gbps microwave link using commercial radios
- World record throughput, 139 Gbps over 1.5 km
- World record spectrum efficiency, 55.6 bps/Hz
- 99.995% availability with 100 Gbps data rate
- 99.99% availability with 125 Gbps data rate

Sucessfully demostrated on April 12, 2019 at Athens



Ex. 64QAM in 2.5 GHz channel bandwidth

Spectrum efficiency: *state of the art*



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Deutsche Telekom and Ericsson top 100Gbps over microwave link

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- Wireless backhaul confirmed as a future-proof technology in 5G era
- Microwave link over 1.5km in live trial achieves 10 times greater throughput than current commercial solutions
- Joint innovation project used Ericsson's latest mobile transport technology

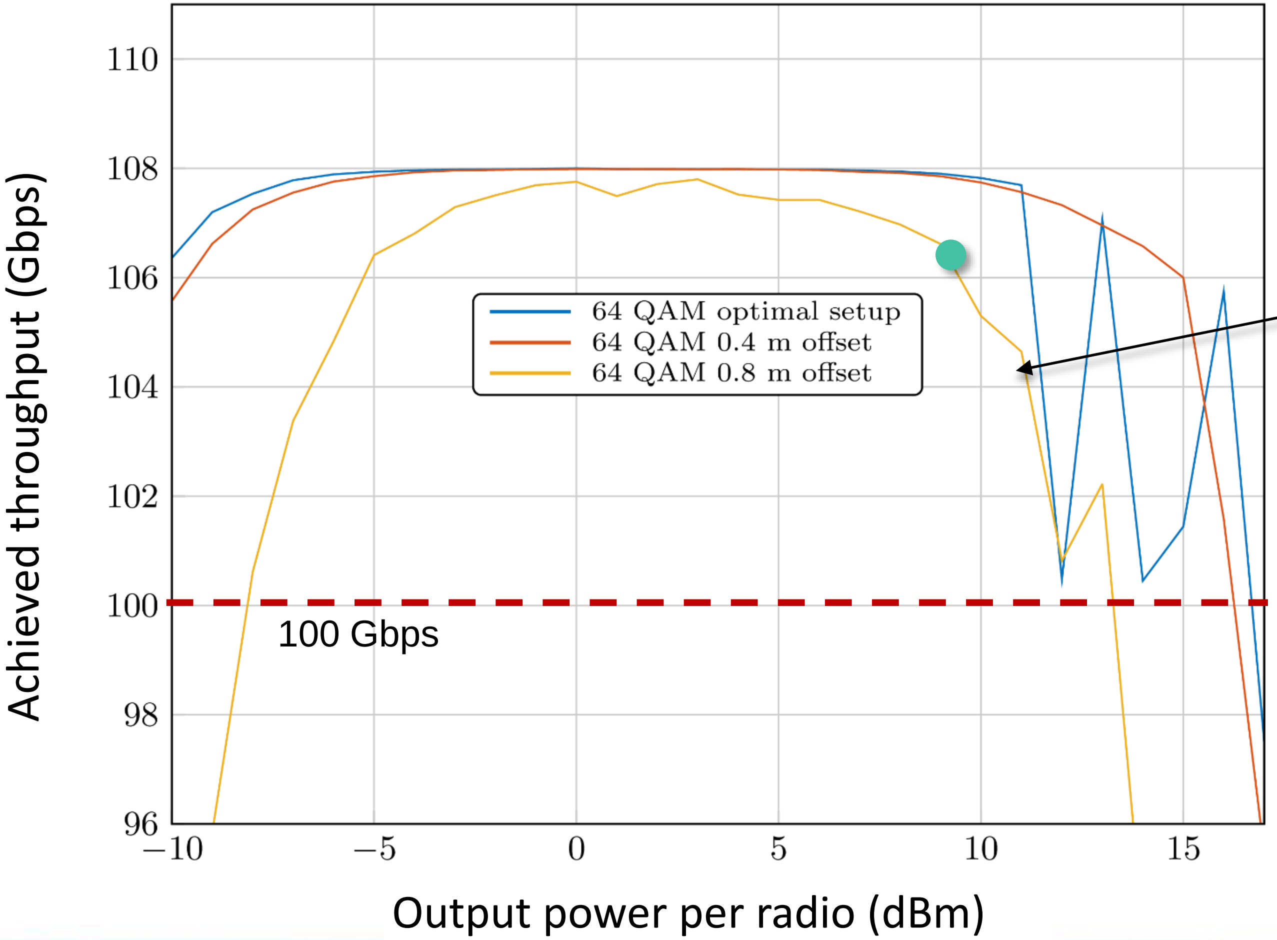
Ericsson (NASDAQ: ERIC) and Deutsche Telekom have achieved a landmark data transmission rate by consistently topping 100 Gbps in a trial microwave link over 1.5km. Conducted at the Deutsche Telekom Service Center in Athens, the joint innovation project represents a major technical breakthrough, achieving more than 10 times greater throughput speeds than current commercial solutions on similar 70/80 GHz millimeter wave spectrum.

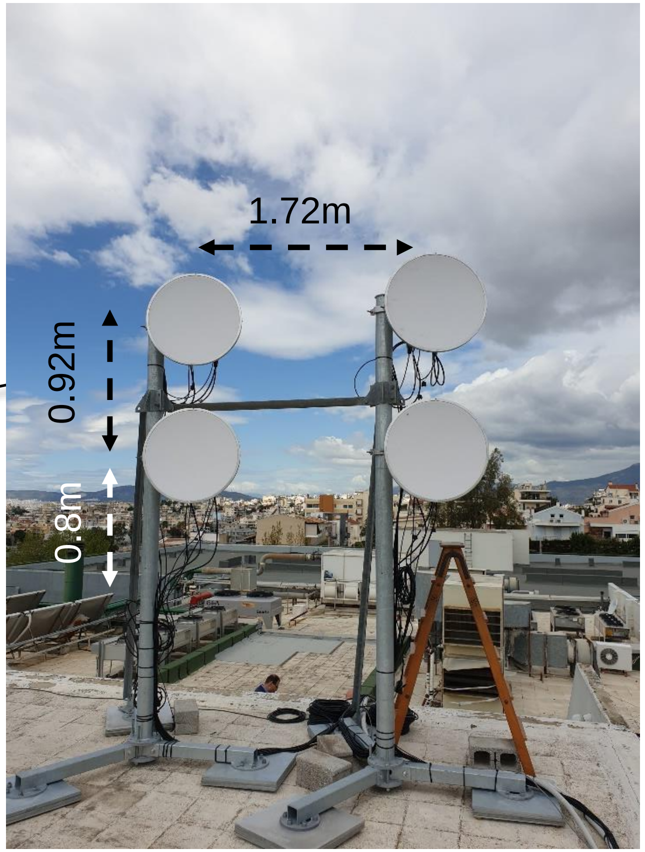
Alex Jinsung Choi, SVP Strategy & Technology Innovation at Deutsche Telekom, says: "Advanced backhaul solutions will be needed to support high data throughput and enhanced customer experience in the 5G era. This milestone confirms the feasibility of microwave over millimeter wave

Throughput at non-optimum antenna separation

>99.995% availability at 100Gbps with optimum sepration and 0.4m offset

>99.99% availability at 100 Gbps for 0.8m offset



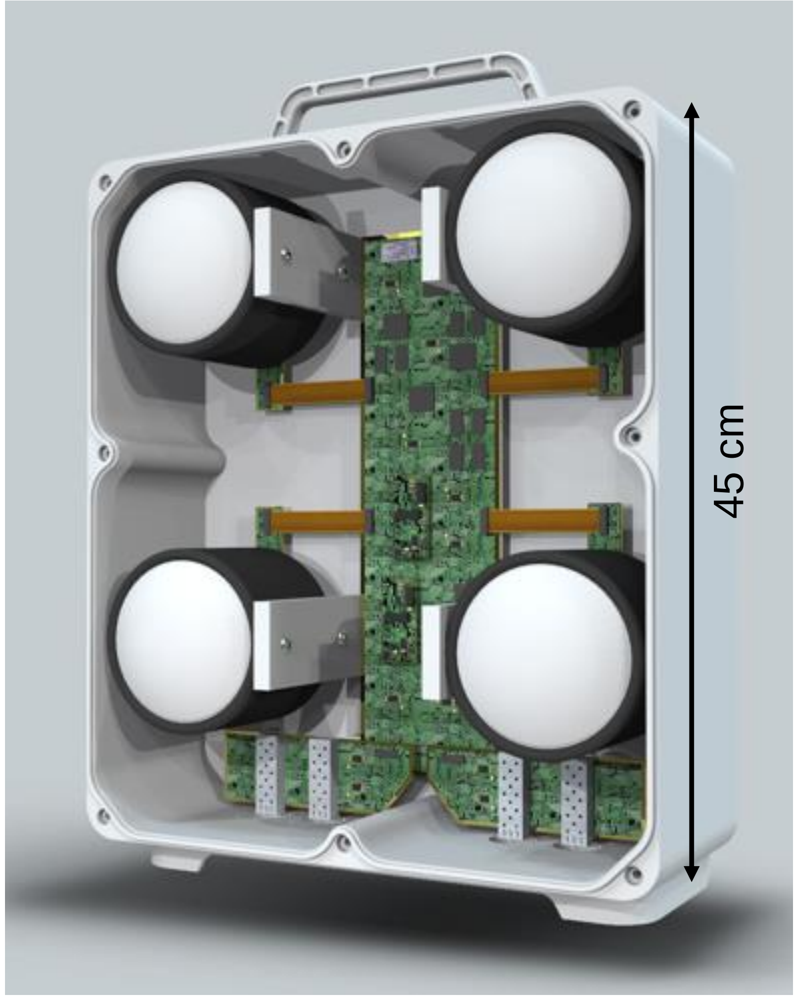


Summary and conclusions

- *Microwave solution:* capable to support the evolution of backhaul networks towards 2025
  - up to 40 Gbps demonstrated using existing E-band radios
- Higher and higher frequencies (>100 GHz) will be taken into use for fixed services, e.g., point-to-points radio links
  - *short-term:* the W- & D-band to be in commercial first
  - *longer term:* towards sub-mmW (up to 275 GHz proposed)
- Chip interconnect and packaging are challenging at mmW & sub-mmW, particularly for Si-based MMICs
  - Heterogenous integration, antenna-on-chip or in-package if possible
- 100+ Gbps microwave link using single carrier frequency is no longer a dream but a reality
  - Microwave: a future-proof solution for beyond 5G

Some future perspective

- High-order line-of-sight MIMO is promising when the frequency goes up,
  - Short hop distance & high frequency ➔ compact antenna arrangement
- With 100 Gbps being achieved, what is the next barrier to break?
  - Tbps microwave is not impossible



A mock-up for 8x8 LoS-MIMO at D-band (target at 200m hop distance)

Acknowledgement

- Dr. Klas Eriksson (Ericsson): for his module test and measurement
- All partners in M3TERA project, especially
  - Dr. Simon He and Prof. Herbert Zirath (Chalmers), for the development of MMICs and the MMIC-to-micromachined waveguide transition
  - Dr. James Campion and Prof. Joachim Oberhammer (KTH), for the design and manufacturing of the micromachined platform
- Part of the presented data are results from M3TERA project funded by EU's Horizon 2020 programme under grant agreement No 644039